THE FUTURE OF HST AND THE PLANNING FOR A NEXT GENERATION SPACE TELESCOPE

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After the success of the refurbishment mission to HST in December 1993, the telescope has taken its place at the very leading edge of astrophysical research. The breadth and depth of the topics covered at the HST conference in Paris in December 1995 gave us a foretaste of the value of the data archive being accumulated and the supreme importance of future observations for guiding and enriching the programmes carried out with Keck and the very large groundbased telescopes nearing completion. Here I outline, as far as we know them, the plans for HST beyond the 1997 and 1999 servicing missions. The current planning for a Next Generation Space Telescope as part of NASA's *Origins* initiative is described with particular emphasis on possibilities for European participation.

1 Introduction

The question of the future of ultraviolet through infrared astronomy from space has recently been reviewed by the 'HST and Beyond' committee chaired by Alan Dressler of the Carnegie Observatories. Their report entitled 'Exploration and the search for origins: A vision for ultraviolet-optical-infrared space astronomy', available from:

`http://saturn1.gsfc.nasa.gov/ngst/Background/HST_Beyond.PDF`

follows and complements the report of the 'Toward other planetary systems' committee chaired by Bernie Burke of NASA's Solar System Exploration Division.

The principal recommendations are:

1. The operation of HST beyond its currently scheduled termination date of 2005 using a much lower-cost operation.

2. The development of a space observatory of 4m or larger aperture, optimised for imaging and spectroscopy over the 1–5 μm wavelength range.

3. The development of the capability for space interferometry.

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In addition, the committee noted how important it is for scientists to explain their motivations, goals and results to the public at large. It is in this spirit that these activities fall under the umbrella of NASA's *Origins* initiative.

This article sketches briefly the schedule for future HST servicing missions and then outlines the plans which are currently being made in the US for a Next Generation Space Telescope (NGST) with an aperture approaching 8m.

2 The future of HST

The future plans for HST servicing missions, currently planned for 1997, 1999 and 2002, are described by Chris Blades in these proceedings and details are given on the STScI Web pages at:

`http://www.stsci.edu/servmiss/servmiss.html`

The two new instruments to be installed during the second mission (STS-82, February 1997) are described here by David Axon and Rodger Thompson (Near Infrared Camera and MultiObject Spectrograph) and by Bruce Woodgate (Space Telescope Imaging Spectrograph).

In 1999, there will be a major reboost of the spacecraft to counteract the orbital decay induced by the Solar maximum. New solar arrays will be fitted and the ESA Faint Object Camera will be replaced by the Hopkins/Ball Advanced Camera for Surveys which is described here by Garth Illingworth.

In 2002, there is an opportunity for one or two new instruments to be installed. NASA are about to issue an announcement of opportunity with a due date for proposals several months after the second servicing mission. There is clear potential for international collaboration in the building of at least one of these instruments.

The plans beyond 2005 are currently uncertain and the possibilities for an extended, low-cost operation are being actively investigated. It is clear that the transition between the scientific operations of HST and NGST will have to be carefully managed within the budgetary constraints. It must be remembered, however, that the NGST will be optimised for longer wavelenghts than HST — which will remain the only major observatory for ultraviolet astronomy.

3 The planning for NGST

Following the first meeting about NGST, at STScI in December 1995, the study has gained considerable momentum and so this section is necessarily a snapshot of the developments which will lead to an interim report in November 1996 and a final report in mid-1997. Up-to-date information on the status of the various study components is available at:

http://saturn1.gsfc.nasa.gov/ngst/

In particular, the study outline at:

http://saturn1.gsfc.nasa.gov/ngst/top/Studyp/STUDYP~1.html

is a compact and interesting reference.

Three independent studies are being carried out and their results will be merged during August and September 1996. These are being carried out by:

- The Lockheed Martin Corporation
- TRW Civil & International Systems Division
- The Goddard-led Study Team

Of these, only the deliberations of the latter were accessible at the time of this meeting and so only these are summarised here.

3.1 Scientific drivers

Four categories of science drivers were considered in shaping the mission of which only priorities 1 and 2 are listed here:

Priority 1 (central to mission)

- See galaxy formation: implies large near-IR telescope optimised for 1–5 μm, radiatively cooled to less than 70K, zodiacal light sensitivity limited, 60–100 mas resolution at 1–2 μm
- Find high-z supernovae: implies wide field cameras with FOV greater than 3$\times$3 arcmin with more than 4096^2 pixels
- 1.5 yr survey, 3.5 yr GO programme: implies lifetime of expendables
- Find first globular clusters: implies collecting area greater than 12m^2
- Measure many z's of 'red' galaxies: implies low spectral resolution '3D' multi-object spectrograph

Priority 2 (very important)

- See star formation (post-ISO/SIRTF): implies thermal-IR 5–30 μm camera/spectrograph
- Study foreground galaxies: implies wide field visible camera

- All-sky pointing once/yr for GOs: defines sunshield shape and need to look perpendicular to sun
- Monitor supernovae for 2.5 months: constrains sunshield shape and angle with respect to sun
- Follow-up for 3 GO cycles: implies 10 year lifetime goal
- $R = 1000$ spectroscopy at $z = 5$ for 5σ sources: implies large aperture, 8m goal

3.2 The working groups

The Goddard-led study has set up several working groups which meet independently but regularly coordinate their activities. These include: an Engineering/Management Study Group; an Industry Advisory Board and groups looking at Operations Systems; the Optical Telescope Assembly; the Science Instrument Module; the Science Performance; the Spacecraft Support System and the NGST Systems. In addition, there is a Science Advisory Committee which provides input to all three studies.

The budgetary guidelines set by NASA for the study are for a spacecraft cost of $M 500 (phase C/D) and a total mission cost (to include launch and operations) of some $M 900. It is clear from this that the mission has to be very different in concept from HST and in particular has to be built quickly using proven technology. The absence of the need for astronaut access, while greatly reducing costs, means a somewhat greater mission risk. The operational costs will also have to be kept strictly controlled.

3.3 A spacecraft concept

At the time of this meeting, the Goddard-led study was concentrating on a passively cooled 8m (almost filled) aperture, diffraction limited at 2 μm. The orbit would be chosen to minimise environmental disturbances, to allow stable communication links and stability for the nominal mission lifetime with minimum observation interruptions and maximum observational opportunities. The trajectory to orbit would be chosen to keep the launch requirements within the limits of available launchers and to keep the transfer time as short as possible. The most promising solution appears to be an 'L2 halo' orbit (in the Sun/Earth system) at a distance of some 1.5 million km from Earth. Such a location has enormous advantages over low-earth orbit by removing

many observing constraints. Communications are easier than with heliocentric orbits and there is full-sky coverage with opportunities for long continuous observations. The stable thermal environment facilitates passive cooling.

The required sun-shield limits the instantaneous pointing of the telescope to a ring with an axis (V3) along the spacecraft-sun vector and with a width which is set by the detailed shield shape but would typically be $+5°/-57°$ from the plane perpendicular (V1-V2) to this vector around the V2 axis (nb. V1 is the optical axis of the telescope).

As a general tool for studying the effect of variations of NGST design on the achievement of the scientific goals (as presented in the 'HST and Beyond' report), the STScI has developed a computer program which computes the fraction of the science programme achieved in a given mission lifetime as a function of telescope aperture. This work is described at:

`http://augusta.stsci.edu/`

The current design of the Optical Telescope Assembly (OTA) is for a segmented 8m aperture with an f/1.25 primary, an f/24 OTA and a 5×5 arcminute FOV. The 4-mirror, centred design has small M3 and M4 mirrors located behind the primary. The primary is re-imaged onto a flat, but deformable quaternary mirror for fine figure control. With the fast primary and off-axis field, there is very little obscuration. A fine steering mirror — fed with an error signal from the main camera — would provide astrometric pointing, avoiding the necessity of providing milliarcsecond *spacecraft* stability. Various concepts for ultra-thin, lightweight mirror panels are being investigated.

The baseline launch vehicle is an Atlas IIAs but it is clear that a larger launcher would allow sufficient aperture for the science programme with a much simpler deployment scheme.

3.4 Instruments

The science instrument suite currently being studied consists of:

- a NIR camera with a 4×4 arcmin FOV using 64 1024^2 InSb (0.6–5 μm) arrays in four optical assemblies — rather like the HST WFPC
- a NIR multi-object spectrograph with a 3×3 arcmin FOV: this and the NIR camera would be passively cooled to less than 40K
- a thermal-IR camera with a 2×2 arcmin FOV using a 1024^2 Si:As array
- finally, a thermal-IR spectrograph would feed the same detector as the TIR camera: these last two instruments would work from 5–26 μm and would need to be actively cooled to about 8K

These four instruments would be packaged together and would use adjacent parts of the focal plane.

3.5 Communications and operations

The data transmission requirements are important because of the relatively large distance from Earth (10s round-trip light travel time). At an estimated 40,000 frames per year (5 Tbyte/yr), the average sustained data rate would be approximately 160 kbyte/s. A single dedicated 11m aperture ground antenna working with dual s-band and x-band frequencies would provide 8h/day coverage. The NASA Deep Space Network would be used only in emergencies.

There are many considerations which determine the operational modes and the nature of the orbit means that they would be different, and generally simpler, than for HST. Using common microprocessors throughout and employing a workstation/network environment would avoid much parallel development of different systems. The number of available observing modes per instrument/detector would be limited to about four and there would be easy mode changes for flexible scheduling. One of the major simplifications compared with the current HST operation would be the use of an autonomous guide star acquisition using a sub-array of the NIR camera. This avoids the need for costly pre-selection of guide stars but may result in the inability to make repeated pointings to exactly the same part of the sky.

This opportunistic pointing control would allow an adaptive scheduling scheme which means that, after observing programme design, there need be relatively little intervention from the ground except for error/problem resolution.

4 European involvement

The NGST feasibility study in the US is proceeding very fast and, judging by the excellent quality of the reports and presentations, it is a serious effort with participants clearly having confidence that the project will proceed. An obvious limitation of the current concept is the small size of the baseline launcher (the Atlas IIAs). A larger launcher would make NGST simpler and cheaper — although not necessarily larger. Since the low cost of the mission will demand a very rapid construction schedule, it is clear that all the required technologies will need to be in place before the building phase of the project. There will be a number of technological studies which need to be carried out and these may be in common with those needed for different components of the *Origins* and other programmes. It is clear also that there will be opportunities for

participation in the operational phase.

Given the very large investment in groundbased facilities by Europe, a substantial involvement both in the future of HST (beyond 2001) and in the NGST is vital for the health and vigour of European astronomy. Such facilities are so mutually complementary that they enormously amplify each others value.

Acknowledgments

I should like to acknowledge the warmth and openness of colleagues at NASA, the STScI and other US organisations who have welcomed — without any formal guarantees of contribution — the participation of ST-ECF staff in these studies.

The viewgraphs prepared for this talk are available on the WWW at:
`http://ecf.hq.eso.org/~rfosbury/Beyond_HST/`